Infrared instrumentation for large telescopes: an alternative approach

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ABSTRACT. I very briefly describe the latest generation near infrared (1–2.5 μm) instruments which are available on, or under development for 'large' ($D\geq$3.5 m) telescopes.
Most of the imagers under construction are limited to relatively small fields, while the spectrometers aim at quite high resolving powers. The alternative instruments which I discuss here are
– WIDE, a relatively low–cost instrument for the prime focus of LBT and/or of TNG optimized for deep imaging of very large fields (12'×12' on LBT and 26'×26' on TNG) through the 1 μm, J, H, K' broad–band filters.
– AMICI, an ultra–high efficiency, low resolution disperser optimized for collecting complete 0.9-2.5 μm spectra of very faint objects. This device is mounted in NICS (the IR instrument for TNG) and should soon deliver spectra with quality comparable to that obtained with instruments on 8m class telescopes with similar integration times.

1. Infrared imagers

Deep multicolour imaging of large fields is one of the most important and popular tools for studying a large variety of astrophysical objects. This simple recognition, together with the recent availability of very large format CCD detectors, has prompted many groups to develop wide field optical cameras for large telescopes. An excellent analysis of the status and performances of these instruments can be found in the WFI–LBT report (Giallongo et al. 1999) which also contains an exhaustive discussion of the scientific cases for deep wide field imaging.
While the astronomical community is taking (or will soon take) advantage from several powerful wide field optical imagers, the situation for imaging in the near infrared (1–2.5 μm) is much less encouraging. Table 1 is a list of all the NIR instruments working, or planned for the next $\simeq$5 years on large telescopes.
In spite of the fact that the latest generation 1024^2 (and soon 2048^2) IR arrays allow coverage of about 10'×10' fields at seeing–limited resolutions, the average field covered by the NIR instruments is much lower. In particular, the situation on the largest telescopes is far from encouraging. On the upgraded MMT, a 5'×5' camera was proposed by the Cambridge's group in 1996 but, to the best of my knowledge, this project has been cancelled. A similar instrument is now proposed by the CfA but its status is still very unclear (see ref. T18).
On 8–10m class telescopes no wide field imager is officially planned apart from NIRMOS, which is indeed a multi–object spectrometer and will be seldom used as an imager.

Table 1 – IR Imagers working or planned on large telescopes

Telescope[a]	Instrument[b]	f.o.v.[c]	Speed[d]	Ref.[e]	Comments
AAO	IRIS2	7.7' × 7.7'	3.1	T1	
WHT	CIRSI	11' × 11'	$\simeq 3^f$	T2	Operating, $\lambda < 1.8\ \mu$m,
WHT	INGRID	4.2' × 4.2'	0.92	T3	
KPNO	IRIM	2.5' × 2.5'	0.33	T4	Operating
CTIO	OSIRIS	3.9' × 3.9'	0.80	T5	Operating
CTIO	CIRIM	1.7' × 1.7'	0.15	T6	Operating
CFHT	KIR	0.6' × 0.6'	0.015	T7	Operating
CFHT	RedEye	2' × 2'	0.16	T8	Operating
Calar-Alto	Ω-prime	6' × 6'	1.4	T9	Operating?
Calar-Alto	Ω-Cass	5' × 5'	1.0	T10	Operating
UKIRT	IRCAM3	1.2' × 1.2'	0.07	T11	Operating
UKIRT	UFTI	1.6' × 1.6'	0.13	T12	Operating
NTT	SOFI	5' × 5'	1.0	T13	Operating
TNG	NICS	4.2' × 4.2'	0.71	T14	
Palomar	P.F. IR cam.	2' × 2'	0.33	T15	Operating (private instr.)
Palomar	Cass. IR cam.	0.6' × 0.6'	0.03	T16	Operating (private instr.)
MMT	CIRSI	5.1' × 5.1'	3.1	T17	Proposed in 1996, cancelled?
MMT	CfA IR cam.	6.8' × 6.8'	5.4	T18	Concept design, phase A started?
VLT-UT1	ISAAC	2.5' × 2.5'	1.4	T19	Operating
VLT-UT4	NIRMOS	12' × 16'	43	T20	Limited to $\lambda < 1.8\ \mu$m
Keck1/2	NIRC1/2	0.64' × 0.64'	0.13	T21	Operating
Gemini	NIRI	2' × 2'	0.88	T22	
Subaru	IRCS	1' × 1'	0.22	T23	
LBT	LUCIFER	4' × 4'	3.7		Phase A started
LBT	WIDE–LBT	12' × 12'	33	T24	Proposed to CNAA,
TNG	WIDE–TNG	26' × 26'	27		phase A completed

[a] Telescopes with $D \geq 3.5$ m which are operating or expected to work in the next few years.

[b] Name of the IR imager available or planned witihin the next few years

[c] Field of view on sky, in arc-minutes.

[d] Speed factor, i.e. time needed to image a given f.o.v. to a given depth, normalized to NTT-SOFI

[e] See the reference list

[f] CIRSI is an "only detector camera" which works with pre–existing optical correctors that have low transmissions in H, typically a factor of ∼2 lower than IR optimized lenses.

Table 2 – Cost estimates for WIDE

Item	cost[a] LBT	cost[a] TNG	Firm
Glass optics and lens holders	215	175	Gestione SILO (Firenze)
Crystal optics	190	175	Janos Techn. (USA)
Crystotat and mechanics	190	220	Rial (Parma)
Filters (1 μm, J, H, K') ⌀80mm	45	120	Barr Ass. (USA)
Electronics–software	130	130	various
Total (w/o array)	770	820	
Array	$\simeq$600[c]	$\simeq$1500	Rockwell

[a] In millions of Italian Lire

[b] Cost of single array could be significantly reduced if purchase order is coordinated with WIDE–TNG or with groups working on other instruments (e.g. Lucifer, Oneiric)

The main consequence of such a situation is that all deep imaging surveys will be severely biased toward sources which are blue enough to be detected by CCDs, while miss intrinsically red objects such as very cool brown dwarfs, elliptical galaxies at $z > 1.5$ and QSOs at $z > 10$ (just to mention a few of the "hottest" subjects). This problem could be alleviated if an instrument like WIDE becomes operative on either the LBT and/or the TNG telescopes. In both cases, the "survey power" would be a factor $\geq$10 larger than any other instrument available or planned (see Table 1). I report here the main results of the phase–A study of the WIDE instrument.

2. The WIDE instrument

The main goal of the WIDE project is to build a simple and relatively inexpensive NIR instrument which could cover the largest possible field of view for seeing limited imaging on 3.5m and 8m class telescopes.

The prime focus of the LBT, with a natural scale of 21"/mm (i.e. 0.38"/pix on a Rockwell HgCdTe array), is the ideal site for such an instrument. Simple considerations on the relative roles of airglow and thermal backgrounds, together with the recent experience of the Ω–prime instrument at Calar Alto, indicate that the prime focus is an

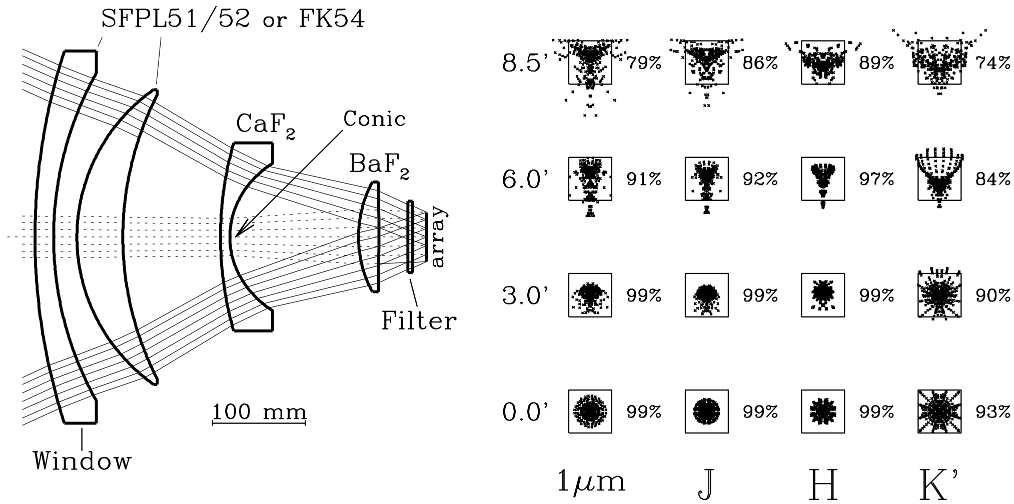

Fig. 1. Left: optical layout of **WIDE–LBT**, the 12'×12' IR camera for the prime focus of the LBT telescope. The first ⊘400 mm lens has very lax centering/tilt tolerances and acts also as window for the dewar.
Right: Polychromatic spot diagrams for imaging through the 1 μm (0.95–1.1 μm), J (1.1–1.4 μm), H (1.5–1.8 μm) and K' (1.95–2.3 μm) filters. The squares are 18.5×18.5 μm (equivalent to 0.352"×0.352" on the sky) and correspond to the size of 1 pixel of the Rockwell HgCdTe array. The spots are shown at various positions from the center (0') to the corner (8.5') of the array and the numbers are the fraction of energy falling within a circle of ⊘18.5 μm. The distortion is 0.5% at 6' (array edge) and 1.0% at 8.5' (field corners).

excellent station to perform IR imaging in the airglow dominated bands, i.e. from 1 μm to K'. Moreover, a prime focus camera is much simpler and consists of much fewer optical elements than Cassegrain instruments with a similar field of view.
More details on the expected performances can be found in the original WIDE proposal that was submitted to the CNAA in May 1998 (see ref. T24) which also includes a quite detailed analysis of the various technological aspects of this instrument. In the last year we concentrated on the opto–mechanical design and verified the feasibility (and estimated the cost) of the various parts by contacting various companies.
Another excellent possibility is to exploit the prime focus of the TNG telescope, in which case it is necessary to use a mosaic of 4x4 arrays to cover an area large enough to achieve a survey power similar to the LBT. Figs. 1,2 show the optical layouts of the instruments. The larger lenses (max ⊘ 400 mm) are manufactured out of standard fused silica (IR grade) or glasses from the Ohara Corp. (SFPL51 and SPFL52) or Schott (FK54) catalogues. All these glasses have negligible internal absorptions at $\lambda < 2.4$ μm.

The smaller lenses are made of calcium or barium fluoride crystals which are regularly produced in large blanks by several companies around the world. The sizes of these lenses is quite standard. In particular, the BaF_2 lens is slightly smaller than the

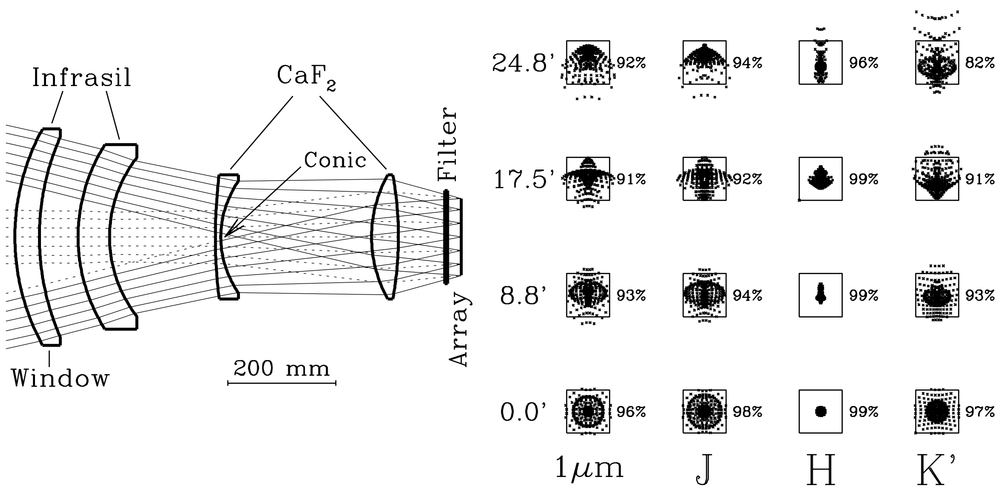

Fig. 2. Left: optical layout of **WIDE–TNG**, the 4×13'×13' IR camera for the prime focus of the TNG telescope. The focal length is 10 m which yields a scale of 0.382"/pix on a Rockwell HgCdTe array. The total corrected field of view is 35'×35' and can accomodate a mosaic of four separated (and losely spaced) 2048^2 detectors. The "Filter" is a mosaic of four 45×45 mm elements, i.e. with sizes which are well within the capabilities of filter manufacturers.
Right: Polychromatic spot diagrams for imaging through the 1 μm (0.95–1.1 μm), J (1.1–1.4 μm), H (1.5–1.8 μm) and K' (1.95–2.3 μm) filters. The squares are 18.5×18.5 μm (equivalent to 0.382"×0.382" on the sky) and correspond to the size of 1 pixel of the Rockwell HgCdTe array. The spots are shown at various positions from the center (0') to the corner (17.5') of the array and the numbers are the fraction of energy falling within a circle of ⊘18.5 μm. The distortion is 0.5% at 17.5' (array edge) and 1.0% at 24.8' (field corner).

collimator of ISAAC while the CaF_2 elements are all significantly smaller than the lenses normally used in UV micro–lithography instruments.
The only non–spherical element is the first CaF_2 lens which has a conical surface: K=–0.22 and K=–0.36 for LBT and TNG, respectively. The sizes and sphapes are within the capabilities of companies specialized in single point diamond machining (e.g. Janos Technology). However, it should be noted that the aspheric on the TNG design, with a maximum deviation from sphere of 290 μm, is much less demanding than that for LBT which deviates up to almost 800 μm.
The system for LBT is virtually free from chromatism and the image quality is excellent, i.e. >80% of the light within one pixel, over most of 12'×12' field of view covered by a single 2048^2 array (see Fig. 1). The image distortion is also quite good: 0.5% at the field edge (6' from axis) and 1.0% at the corners (8.5' from axis).
The design for TNG, which employs the much more dispersive (but cheaper) infrasil glass, requires refocussing in the various bands and provides excellent images (see Fig. 2) over a spectacularly large field of view, namely 35'×35', with an image distortion of only 0.5% and 1% at the field edges and corners, respectively. This is sufficient to accomo-

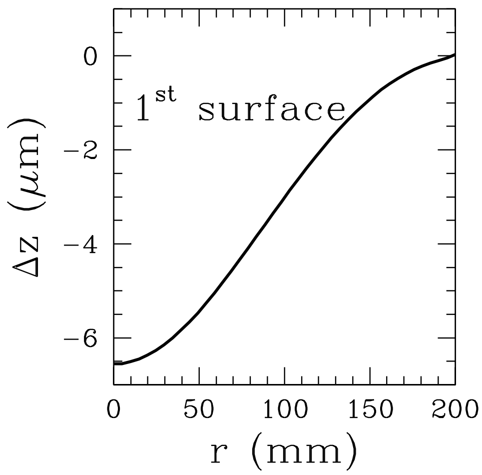

Fig. 3. Deformation of the first lens (see Figs. 1,2) when this optical element is used as window of the dewar. The curves are based on finite element analysis and include the effect of pressure difference (1 atmosphere between the outside environment and the vacuum tank) and weight. The latter amounts to only <0.06 μm and is therefore totally negligible.

date a mosaic of four non–buttable 2024^2 array each of them covering an area of 13'×13'.

A specific advantage of both designs is that the positioning of the first lens has very lax tolerances: a decenter of 0.5 mm and/or a tilt of 0.1 degrees can be fully compensated by shifting/tilting the whole dewar and, in practice, produce a negligible effect on the image quality. Therefore, the first lens can also act as the dewar window without requiring any special mechanical mount. The deformations induced by the pressure difference between the outside environment (air) and the inner vacuum amount to several microns (cf. Fig. 3) but have a totally negligible effect on the image quality.

The cost estimate is summarized in Table 2 which also includes the names of the companies which we already contacted for the various items. Note that the overall cost of the instrument is dominated by the price 2048^2 Rockwell array(s), expecially in the case of the instrument for the TNG which requires four such devices.

3. Low dispersion spectroscopy: the AMICI device

Low dispersion IR spectroscopy covering the widest possible wavelength range is a fundamental tool for studying very faint objects with broad spectral features. These include:
– elliptical galaxies at $z > 1.5$ which can be recognized by the 4000 Å break characteristic of relatively old stellar populations (e.g. Soifer et al. 1999)
– methane dwarf stars, i.e. brown dwarfs cooler than 1500 K and whose spectrum is characterized by the prominent CH_4 band–head at 1.6 μm as well as by the very broad H_2O bands which extend into the J, H and K bands (e.g. D'antona et al. 1999).

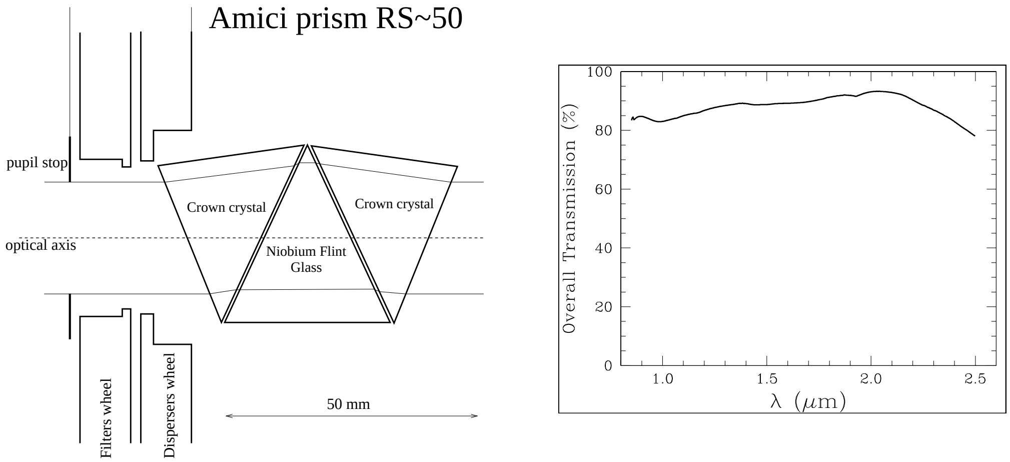

Fig. 4. Left: sketch of the AMICI disperser which consists of 3 prisms organized in the classical Amici mount. The highly dispervive Flint prism, with a vertex angle of 50^o, yields a value of RS (i.e. resolving power with a 1" slit) of about 50.
Right: measured efficiency of the device, note that the overall transmission exceeds 80% over the entire 0.85–2.45 μm wavelength range.

All the existing/planned IR spectrometers for large telescopes employ gratings and/or grisms as light dispersers. This choice intrinsically limits the spectral coverage to 1 or at most 2 photometric bands (e.g. J+H or H+K) per frame. The average efficiency of the grating/grism over the spectral free range is <50% including the losses introduced by the order sorter filter.

The alternative approach which we adopted in NICS, the IR instrument for the TNG, is to use a prism–based disperser which is sketched in Fig. 4. The Crown–Flint–Crown symmetrical combination corresponds to the classical Amici mount with, however, separated (not glued) elements. The resolving power is RS$\simeq$50 and the average efficiency we achieved with ad–hoc multi–layer A/R coatings exceeds 80% (with peaks >90%) over the full 0.85–2.45 μm range (See Fig. 4).

To estimate the "speed" of this device it is convenient to compare the NICS–AMICI combination with the ISAAC–LR spectroscopic mode. The latter uses a grating disperser with average efficiency (within each band) of 50% and requires 4 different exposures to cover the 0.9–2.5 μm range. The AMICI disperser has an efficiency a factor 1.8 higher and delivers the full spectrum in a single shot. Therefore, the factor of $\simeq$7 gain in time one has using AMICI on the TNG should fully compensate the factor of 5 loss due to the lower area of the TNG relative to the VLT. In other words, AMICI on the TNG should soon produce low resolution spectra with similar quality, and with similar integration times, as ISAAC on the VLT.

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